EXPERIMENTAL WORK TO MEASURE COOLING TEMPERATURE OF AN ELECTRICAL UNIT WITH HEAT GENERATION

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Abstract

The satisfactory performance of electrical equipments depends on their operating temperature. In order to maintain these devices within the safe temperature limits, an effective cooling is needed. Cooling process of this equipment was important to save it from temperature rising, which are major causes of failure. Fan with constant low speed at one direction of air flow was used for cooling to measure the reducing of heating temperature through working of this equipment.

Experimental work was done to measure the spatial and temporal distribution of temperatures profile at different locations of the sample, by using a computerized temperature meter (CTMO1). A rectangular box of brass alloy was used as a sample of electrical equipment. The heat transfer coefficient values were found at the side and top of equipment through both processes of cooling and heating. The experimental results were agree well for prediction results for two theoretical models in heating and cooling process with error percentage about 6% to 15% of *Hameed, 2010*.

الخلاصة

إن تقنية عمل الوحدة الكهربائية تعتمد على الحرارة المتولدة خلال عمل هذه الوحدة. لغرض حماية هذه المعدات من الحرارة المتولدة نتيجة العمل لذا يجب تبريدها لتعمل ضمن مدى محدد لدرجات الحرارة بحيث لا تؤثر على عملها وتؤدي إلى فشلها.

تضمن البحث دراسة عملية حيث تم عمل صندوق بشكل متوازي مستطيلات مصنوع من سبيكة البراص كنموذج لوحدة كهربائية لغرض قياس درجة الحرارة المتولدة في الوحدة الكهربائية أثناء عملها خلال الزمن قبل تبريدها. كذلك تضمن العمل أيضا دراسة عملية لتبريد هذه الوحدة لغرض تقليل درجة الحرارة المتولدة بواسطة استخدام مروحة ذات سرعة ثابتة وتكون حركة الهواء لهذه المروحة حركة أفقية ثابتة باتجاه x-axis. تم استخدام جهاز (Interface) في قياس درجة الحرارة حيث يستلم الاستجابة نتيجة تسليط الحرارة وخزنها ومن ثم معالجتها بواسطة برنامج صمم لهذا الغرض حيث تحول هذه الاستجابة إلى حرارة مع تغير الزمن. وقد تم خلال البحث حساب قيمة معامل التوصيل الحراري للهواء (h) ولحالتي التسخين والتبريد.

أثبتت النتائج العملية تقارب مع النتائج النظرية لحالتي التسخين والتبريد مع *Hameed, 2010* وقد حددت نسبة الخطأ في التقارب بحدود 6% إلى 15% .

1. Introduction

In electronic equipment the temperature of the components must not exceed a permitted value to protect them from thermal damage. Both natural and forced convection air cooling are the most important thermal control methods and often preferred to maintain the temperature of electrical equipment with low power and packaging density below an acceptable level. *Ahmed et al., 2005* conducted a series of experiments inside an electronic box. The experimental data were used to develop a general experimental model $Nu=0.03[A_e/A_o]\ Re^{0.8}\ Pr^{1/3}$. This model can predict both the maximum and average temperature inside a closed electronic box with the range of $10^4 \leq Re \leq 10^5$ and $1 \leq A_e / A_o \leq 2.3$. Where A_e total effective area of components, A_o surface area of duct. The enclosure containing electronic components. These components would be a power supply, including heat sinks and a cooling fan inside a box. The electronic enclosure was isolated from the surroundings but the inlet and outlet remained open to allow for unrestricted air flow. The operating inlet velocity, range of the fan inside the box was $0.5 < v < 1$ m/s. The power dissipation was varied within the range of 210 to 255 W. The combined effect of free convection and heat radiation was measured experimentally by operating the box at different power without the fan. *Felczak and Wiecek, 2008* confirmed experiments and simulations that the thermal wake effect (i.e When fluid moves along the board, the components placed upstream have better cooling conditions than the ones placed downstream. It happens because moving fluid warms up) can play an important role for electronic systems cooling. Two flat heat sources placed one after, another cooled with forced laminar convection. From experiments, the results of high dissipated power velocity changes do not play such a role as for a small. Temperature differences seem to be the same for the whole speed range. In order to improve cooling conditions, the additional elements can be added on the PCB to change air flow direction.

The present work is concerned with experimental investigation of natural and forced convective air cooling of rectangular casing with heat source generated per unit volume of this a closed casing. This rectangular case was assumed as closed electrical equipment, which was cooling by fan with constant velocity 0.9195 m/s (i.e. forced convection). Temperatures field in different points were measured with thermocouples at different arrays in top and side wall, and corners of the casing without cooling and with cooling by forced convection. In this study, the effect of the air behavior was not including. It has been shown how this air was effected the temperatures which were generated by heater.

2. Equipment Assembly

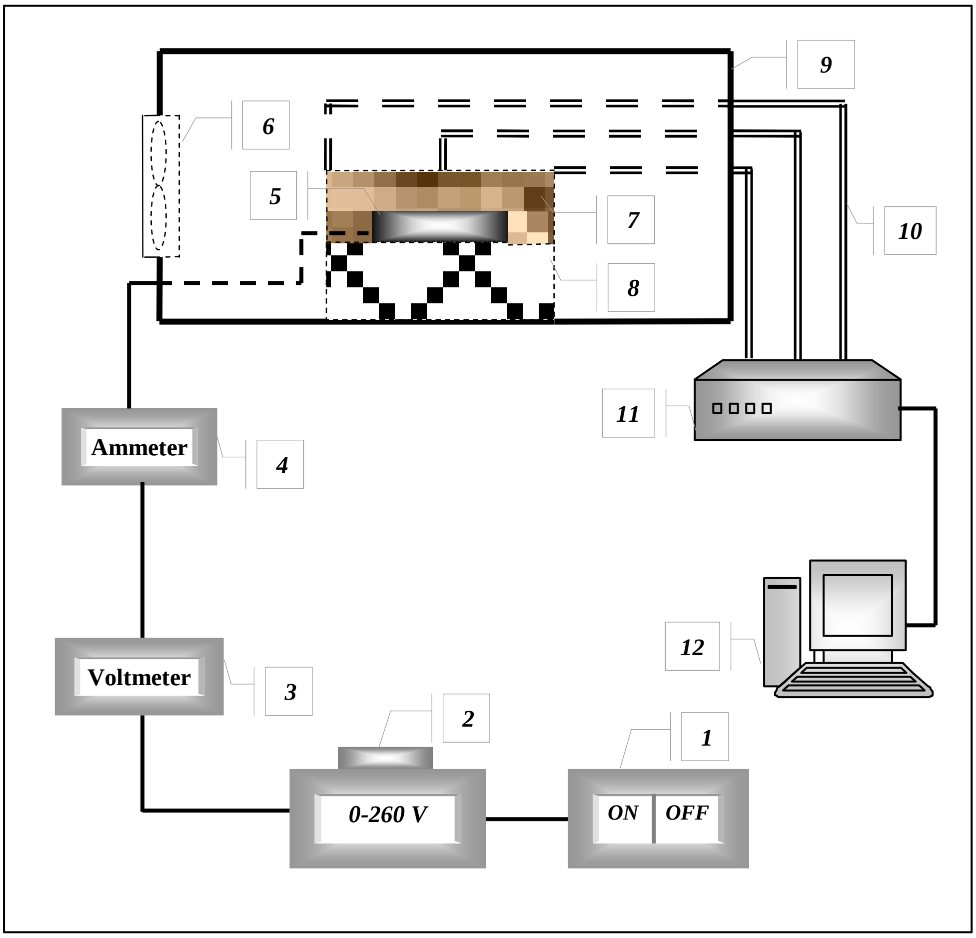
Figure (1) shows the schematic diagram of rig used in the present study. The dimensions of the brass box sample are (20 cm × 20 cm × 6 cm) length, width, height respectively. Circular plate heater with 15 cm in diameter was fixed at the bottom surface of rectangular box sample in order to work as a heat source. This heater gives nearly 1000 W at full load. This value allowed making several tests at range 25 W and 70 W. These ranges of power gave heat generation per unit volume of closed casing as 10416.666 W/m^3 and 29166.666 W/m^3.

Voltage variation device was used to control the value of power supply to the heater. Copper-Constantan thermocouple type T was used to measure the temperature distribution at different positions of closed casing sample through heating and cooling processes. The rectangular box was made by brass alloy, the alloy combination 70% Cu and 30% Zn. In this study eleven thermocouples were used to measure temperature at different locations on the closed casing, figure (2) shows photograph rig of equipments. Thermocouples were calibrated using results produced by *Alwan, 1989* who used correction temperature equations depending on the number of thermocouples. A program code (NOEDREG 164) was used to compare the resistance thermometer temperature with thermocouple temperature to obtain the true temperature for every thermocouple, hence the constant a_0 , a_1 , a_2 and a_3 were determined. The general equation is:

$$T_{true} = a_0 + a_1 T + a_2 T^2 + a_3 T^3 \tag{1}$$

A computerized temperature meter (CTMO1) was used to record the temperature readings at different positions upon sample surfaces. These equipments have facilities to read spatial and temporal distribution of temperature by special software, which was built. This interface equipment gave more reliable and minimizes error through the measurement. it can transform (15) thermocouples reading to digital readings at the same time. The temperature range recorded by this device is (0 to 200 $^{\circ}$C), the time recorded represented a true time between time steps because it is programmed to calculate the real time required. This device was calibrated by *Jassim, 2008* this calibration showed that the reading must be started after 18 seconds from the switching on off (CTMO1) in order to give more stability for readings. The correction temperature equation for every thermocouple gives more reliable results for temperature measurement.

A remote vane digital anemometer RS232 model 8910 was used to measure the mean velocity of air inside a cabinet. Through the measurement, it should be placed in the path of air stream with making sure that the air stream and the sensor are aligned (±20°). The reading has been taken after three seconds in order to stabilize. The specification of this device are: velocity range 0.4 - 35 m/s, resolution 0.01, accuracy ± 0.02, fan diameter 70 mm, dimensions of this device 181mm (L) × 71mm (W) × 38mm (D).



1	*Power supply.*	*7*	*Sample.*
2	*Voltage control device 0-260 V.*	*8*	*Glass wood.*
3	*Voltmeter*	*9*	*Cabinet of wool.*
4	*Ammeter.*	*10*	*Thermocouple.*
5	*Heater.*	*11*	*Interface.*
6	*Fan.*	*12*	*Computer.*

Fig.1 schematic diagram of rig.

Fig.2 photograph rig of equipments.

3. Experimental Procedure

After preparing the computer and the (CTMO1) device, the power was supplied to the heater, and then heat has been generated inside the rectangular box, computer start recording and saving results in files. Values of temperature were tabled with time in a certain point on the rectangular box (i.e. at different locations on a surface of the box) as shown in figure (3).

Two stages of experimental work were done:

1- Measuring the temperatures distribution at different points as shown in figure (3), at two values of power 25 and 70 watt respectively. These measuring were recorded by (CTMO1), when heating this box by heater through interval time 0.5 second at atmospheric pressure and air with ambient temperature 20°C without using fan (i.e. natural convection).

2- Repeat again the measuring of temperatures distribution at the same two values of power heating. These measuring were recorded through interval time 0.5 second by using fan with air velocity 0.9195 m/s in order to exhaust hot air outside the cabinet (i.e. cooling by convection).

All temperature readings were calibrated by using the calibration equations as presented in *Alwan,1989* in order to get accurate results for the measurement of temperatures distribution through all surfaces of the rectangular box. Tables (1) to (4) show (CTMO1) temperature readings of thermocouples location as shown in figure (3) at different times after calibration for heating and cooling process with two powers 25W and 70W respectively.

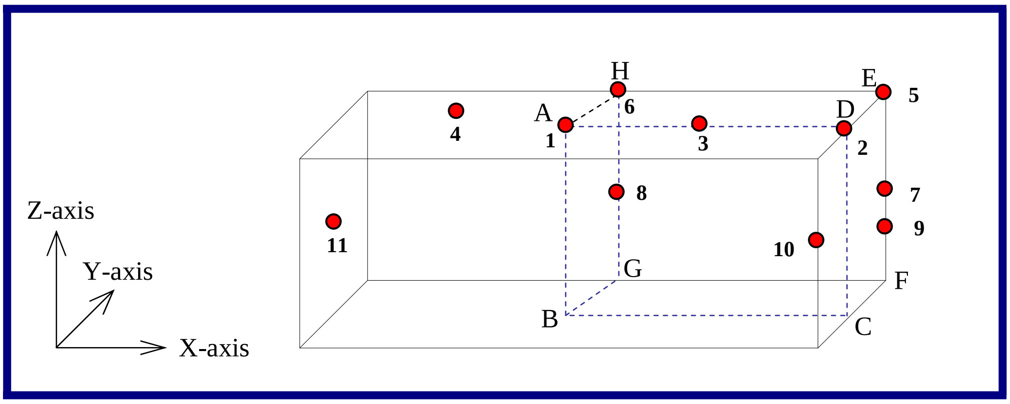


Fig.3 schematic diagram of thermocouples location on rectangular box at experimental work.

Table 1 (CTMO1) temperature readings of thermocouples location as shown in fig. 3 at different times without fan operation at power 25 W.

Time (s)	T_1 (℃)	T_2 (℃)	T_3 (℃)	T_4 (℃)	T_5 (℃)	T_6 (℃)	T_7 (℃)	T_8 (℃)	T_9 (℃)	T_{10} (℃)	T_{11} (℃)
900	33.728	27.849	31.925	31.144	26.61	30.084	33.261	33.155	33.113	32.640	30.393
1800	44.164	40.682	41.534	37.331	35.621	40.075	36.205	40.193	37.444	35.559	40.138
2700	53.561	43.981	46.519	40.083	38.974	44.954	41.993	45.830	42.419	40.970	48.248
3600	60.425	50.851	52.177	43.212	42.161	50.422	44.843	51.118	46.774	43.844	52.670

Table 2 (CTMO1) temperature readings of thermocouples location as shown in fig. 3 at different times with fan operation at power 25 W.

Time (s)	T_1 (℃)	T_2 (℃)	T_3 (℃)	T_4 (℃)	T_5 (℃)	T_6 (℃)	T_7 (℃)	T_8 (℃)	T_9 (℃)	T_{10} (℃)	T_{11} (℃)
900	23.370	20.523	28.819	18.266	18.597	19.621	18.283	19.347	20.495	18.556	20.771
1800	31.348	25.971	27.403	22.664	21.479	23.208	22.634	24.967	25.652	21.425	26.281
2700	37.803	32.429	34.856	25.401	25.667	31.469	28.975	30.043	29.897	27.647	34.048
3600	42.888	37.913	40.192	29.323	27.825	37.797	30.539	38.249	35.532	28.962	40.093

Table 3 (CTMO1) temperature readings of thermocouples location as shown in fig. 3 at different times without fan operation at power 70 W.

Time (s)	T_1 (℃)	T_2 (℃)	T_3 (℃)	T_4 (℃)	T_5 (℃)	T_6 (℃)	T_7 (℃)	T_8 (℃)	T_9 (℃)	T_{10} (℃)	T_{11} (℃)
900	49.359	40.177	42.472	39.917	37.434	42.832	37.131	43.505	40.172	37.53	43.753
1800	66.710	54.372	57.351	42.938	46.162	54.435	48.019	57.906	52.185	47.781	56.422
2700	85.323	62.607	69.953	48.504	53.007	64.021	56.825	67.451	60.886	55.137	72.546
3600	98.893	73.281	80.127	55.394	60.022	78.282	64.405	80.258	69.581	63.361	82.632

Table 4 (CTMO1) temperature readings of thermocouples location as shown in fig. 3 at different times with fan operation at power 70 W.

Time (s)	T_1 (℃)	T_2 (℃)	T_3 (℃)	T_4 (℃)	T_5 (℃)	T_6 (℃)	T_7 (℃)	T_8 (℃)	T_9 (℃)	T_{10} (℃)	T_{11} (℃)
900	28.511	25.387	26.806	20.355	18.566	24.219	20.612	25.032	23.034	19.345	24.532
1800	50.946	38.319	42.059	24.502	25.111	35.298	31.654	35.288	34.659	27.408	42.004
2700	60.366	43.591	53.014	31.868	35.139	47.498	41.918	49.074	45.239	38.847	53.095
3600	81.258	58.226	66.151	38.461	42.456	59.487	47.071	63.704	58.091	44.070	66.152

Also, the average heat transfer coefficient for the side and top surface of the rectangular box was calculated by using equation (2) depending upon the temperature recording through two values of power was fixed. Then used one average value of (h) for the side and top surface of different values of time recording at every power supply for both processes. This was consistent with work of *Hemida and Krajnovic, 2007*. *Karlekar and Desmond, 1982* show how to calculate the heat transfer coefficient as:

$$h = \frac{P - Q_{rad.}}{A_P\left(T_w - T_\infty\right)} \qquad (2)$$

Where Q_{rad} (W) is the heat energy carried away from the surface of box due to radiation, P power (W), A_P: total surface area of the radiant surface (m^2), T_∞: the temperature of the air inside cabinet (^oC), and T_w: temperature of the plate surface of box (^oC).

Tables (5) to (8) show (CTMO1) temperature readings of air and average wall temperature for the sample inside cabinet for heating and cooling processes with two powers 25W and 70W respectively.

Table 5 (CTMO1) temperature readings of air and average wall temperature for the sample inside cabinet without fan operation at power 25 W.

Time (s)	$T_{air\ above}$ (°C)	$T_{W\ average\ top}$ (°C)	$T_{air\ side}$ (°C)	$T_{W\ average\ side}$ (°C)	$h_{av.}$ ($W/m^2\ ^oC$)
900	20.841	32.223	19.904	31.512	55.907
1800	23.594	39.90	22.285	37.907	
2700	26.223	44.678	22.651	43.892	
3600	29.561	49.874	24.157	47.849	

Table 6 (CTMO1) temperature readings of air and average wall temperature for the sample inside cabinet with fan operation at power 25 W.

Time (s)	$T_{air\ above}$ (°C)	$T_{W\ average\ top}$ (°C)	$T_{air\ side}$ (°C)	$T_{W\ average\ side}$ (°C)	$h_{av.}$ ($W/m^2\ ^oC$)
900	19.703	21.532	19.353	19.490	101.5
1800	22.128	25.345	21.936	24.255	
2700	22.549	31.27	22.0	30.122	
3600	22.610	35.989	22.241	34.675	

Table 7 (CTMO1) temperature readings of air and average wall temperature for the sample inside cabinet without fan operation at power 70 W.

Times (s)	$T_{air\ above}$ (°C)	$T_{W\ average\ top}$ (°C)	$T_{air\ side}$ (°C)	$T_{W\ average\ side}$ (°C)	$h_{av.}$ ($W/m^2\ ^oC$)
900	21.461	42.032	21.071	40.418	78.176
1800	25.385	53.661	24.258	52.463	
2700	27.419	63.902	26.511	62.569	
3600	28.200	74.333	27.004	72.047	

Table 8 (CTMO1) temperature readings of air and average wall temperature for the sample inside cabinet with fan operation at power 70 W.

Times (s)	$T_{air\ above}$ (°C)	$T_{W\ average\ top}$ (°C)	$T_{air\ side}$ (°C)	$T_{W\ average\ side}$ (°C)	h_{av} ($W/m^2\ ^oC$)
900	21.703	23.974	20.162	22.511	149.491
1800	21.719	36.039	21.375	34.202	
2700	21.74	45.634	20.766	45.213	
3600	22.283	57.673	21.058	55.817	

4. Results and discussion

Through the experimental work eleven thermocouples type T were fixed at different positions on the electrical equipment (rectangular brass box). The thermocouples measured the temperatures of different points on electrical equipment as shown in figure (3) by using a computerized temperature meter (CTMO1). Figures (4) and (5) show the temporal variation of temperature profiles in numbers of thermocouples measurement which were fixed at different positions on right side plane of the rectangular brass box at two values of heat source for heating and cooling this electrical equipment. These points represented thermocouples number 9, 7, 10, 5 and 2 as shown in figure (3). It has shown the temperature of heating and cooling increasing with time. At time 3600 seconds, and at two values of heat sources, the maximum temperature values were measured through heating process at point 2, while the maximum reducing of temperature by fan through cooling process was recorded at point 10, which was about 19^{o}C at the first value of heat source, and 15^{o}C at the second value of heat source. This is due to the position of these two points for the heat source and the fan air flow.

Figures (6) and (7) represent the spatial temperature distribution of z-axis in right side plane of points 9, 7, 10 and 5 for time intervals 900 seconds through heating and cooling process at two values of heat source. It has shown the similar of relationship response for cooling and heating through these two values of heat source, only different in the level values of temperatures. It was described the maximum value of temperature measured at distance close to base of the box in z-axis, and the temperature decreasing faraway from the base (i.e. faraway from point 9). The shape response of relationship in heating and cooling for these two figures were linear exponential. Very small negative gradient appeared through cooling process only at time level 3600 seconds for two values of heat source.

Figures (8) and (9) illustrate isothermal contour map of heating process for right side plane (y-z plane) at time level 3600 seconds and heat sources were 29166.666 W/m^3 and 10466.666 W/m^3 respectively. It has been indicated that the measurement temperature was a higher at the center of plane (i.e. center of brass box) and starting to reduce faraway from center of electrical equipment. This is due to the center of base was more closed to heat source and received high energy than other points of electrical equipment.

Figures (10) and (11) show the isothermal contour map of cooling process for right side plane (y-z plane) of this equipment at time value 3600 seconds and two values of heat sources. It has been shown that the response of reduction temperature through cooling process was similar at two level values of heat source. It was higher reduction of temperature at the top of plane than the base of plane (i.e. more cooling rate). That means the fan efficiency of cooling at the top of y-z plane more than the base of this plane. This was depends upon the values of temperature distribution of brass box due to the heat transfer mechanism of inside volume of the brass box and heat source. That was consistent with behavior of heat transfer mechanism, which was described by *Holman, 2002.*

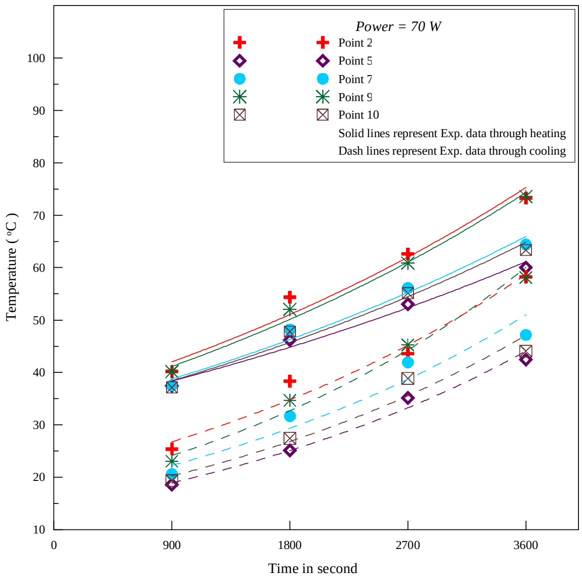


Fig. 4 temporal variation of temperature at points (9, 7, 10, 5 and 2) in right side plane of brass box.

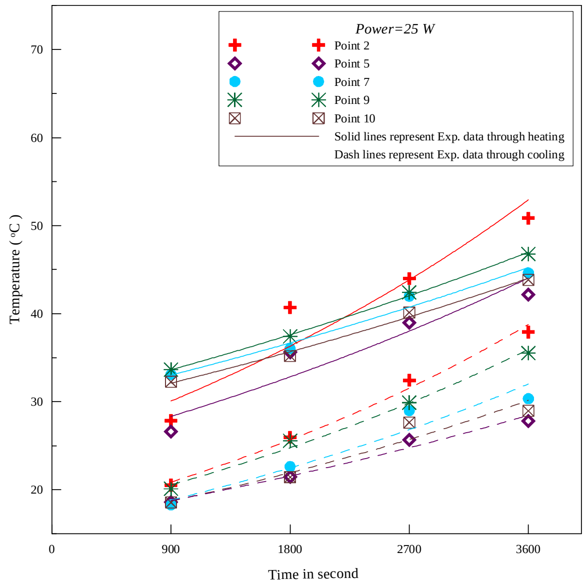


Fig. 5 temporal variation in temperature at points (9, 7, 10, 5, and 2) in right side plane of brass box.

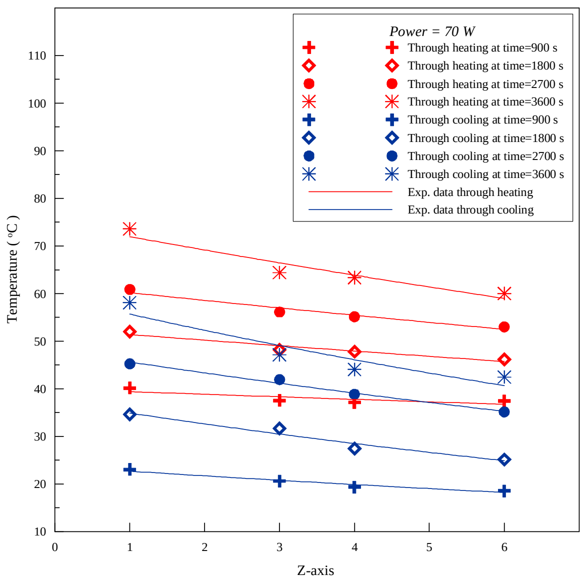


Fig. 6 spatial temperature distribution of z-axis in right side plane (points 9, 7, 10 and 5) for different heating and cooling times of brass box.

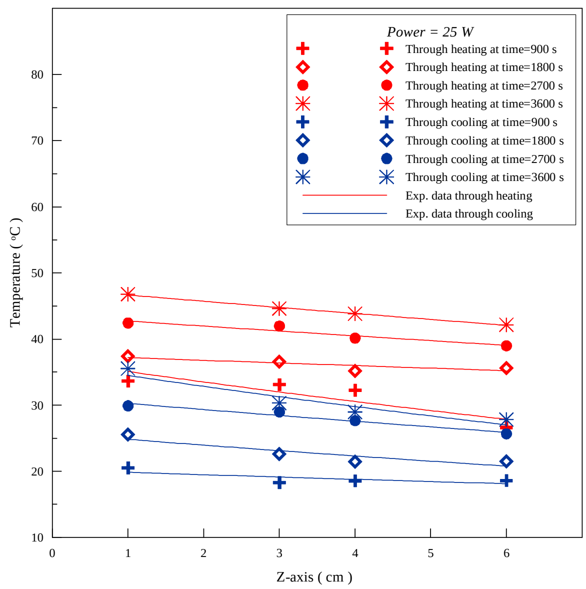


Fig.7 spatial temperature distribution of z-axis in right side plane (points 9, 7, 10, and 5) for different heating and cooling times of brass box.

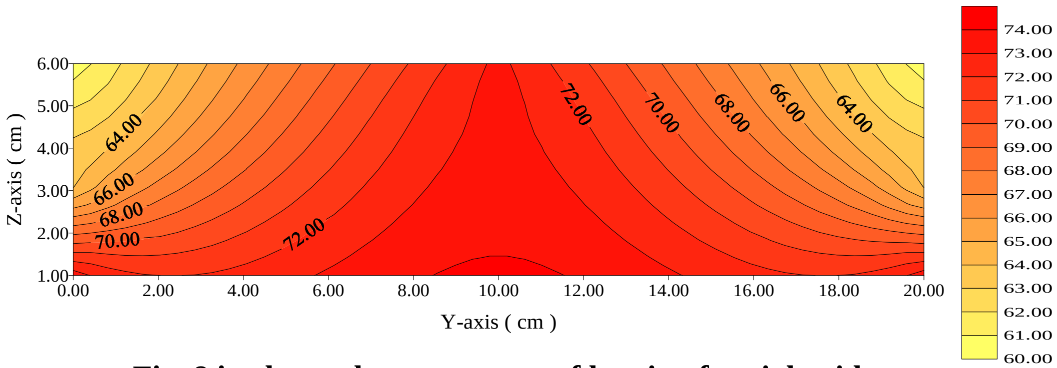


Fig. 8 isothermal contour map of heating for right side plane of brass box with power 70 W, and time ٣٦00 s

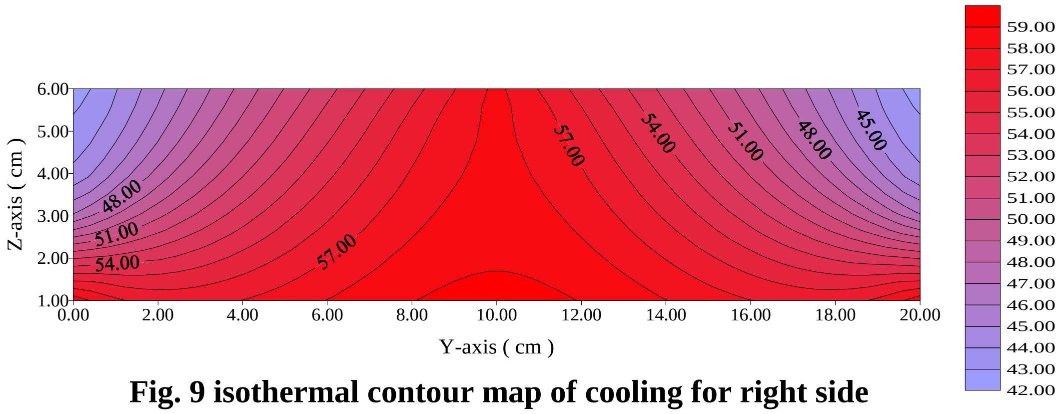


Fig. 9 isothermal contour map of cooling for right side plane of brass box with power 70 W, and time ٣٦00 s.

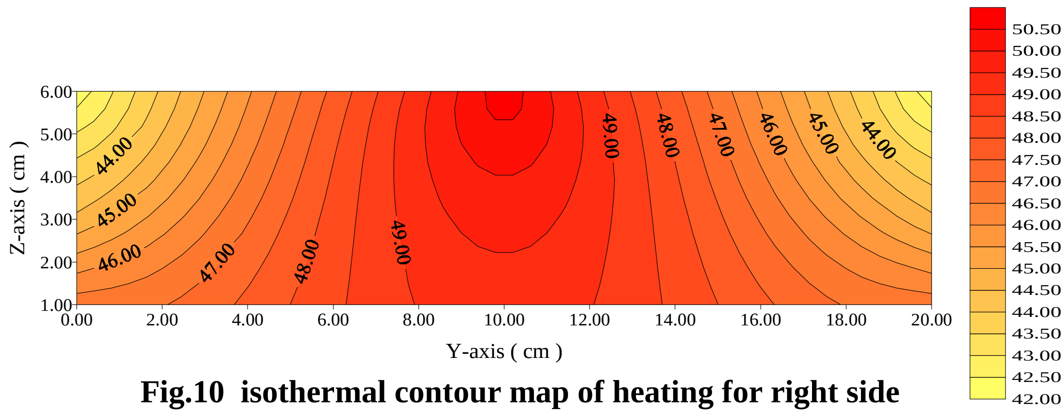


Fig.10 isothermal contour map of heating for right side plane of brass box with power 25 W, and time ٣٦00 s.

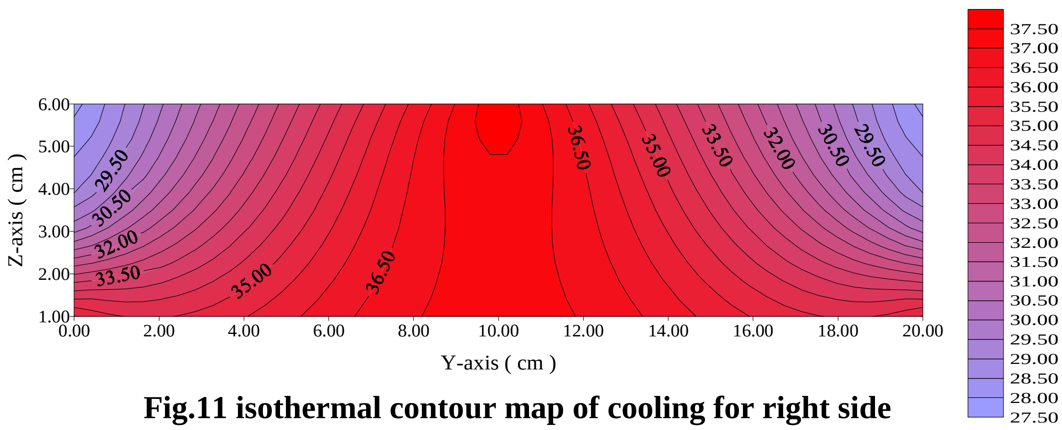


Fig.11 isothermal contour map of cooling for right side plane of brass box with power 25 W, and time ٣٦00 s.

5. Conclusions

1. Experimental work was done by using advanced equipment in order to measure the temperature distribution through two processes of this equipment. A computerized temperature meter (CTMO1) was used to record the temperature readings at different locations on the equipment. These test equipments have facilities to read the spatial and temporal distribution of temperature by special software, which was built. This interface equipment gave more reliable and minimizes error through the measurements.
2. It was found that the experimental measurement of temperature distribution through heating and cooling process with selecting different values of electrical power supply were well as agree with prediction results for two models of *Hameed, 2010*.
3. Average heat transfer coefficient was calculated for both processes with two powers, the results indicated that the average heat transfer coefficient increase significantly with increase power and with increasing air velocity.

6. References

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